N91-32736

INFLUENCE OF CHANNEL BASE CURRENT AND VARYING RETURN STROKE SPEED ON THE CALCULATED FIELDS OF THREE IMPORTANT RETURN STROKE MODELS

Rajeev Thottappillil Martin A. Uman

Department of Electrical Engineering
University of Florida
Gainesville
Florida

Gerhard Diendorfer

Department of Electrical Power Engineering
Technical University of Vienna
Vienna
Austria

ABSTRACT

Recently Nucci et al. [1] compared five return stroke models using an identical current at the channel base of each. Diendorfer and Uman [2] introduced a new model which reproduces remarkably well the experimentally observed characteristics of the fields both close to and far from the return stroke channel. Both Nucci et al. [1] and Diendorfer and Uman [2] used a channel base current that is typical of measured subsequent stroke current of both natural lightning and triggered lightning. Though the channel base current adopted in each paper is within the range of measured currents , they differ in the detailed wave shape. The first part of this paper compares the calculated fields of the Traveling Current Source (TCS), Modified Transmission Line (MTL), and the Diendorfer-Uman (DU) models with a channel base current assumed in Nucci et al. [1] on the one hand and with the channel base current assumed in Diendorfer and Uman [1] on the other hand. The characteristics of the field wave shapes are shown to be very sensitive to the channel base current, especially the field zero crossing at 100 km for the TCS and DU models, and the magnetic hump after the initial peak at close range for the TCS model. In the second part of the paper the DU model is theoretically extended to include any arbitrarily varying return stroke speed with height and a brief discussion is presented of the effects of an exponentially decreasing speed with height on the calculated fields for the TCS, MTL, and DU models.

INTRODUCTION

There are a number of lightning return stroke models that have been used to calculate remote electric and magnetic fields given an assumed current at the base of the channel and an assumed speed of the return stroke. Nucci et al. [1] compared five of the most used models, namely, Bruce-Golde (BG), Transmission Line (TL), Master-Uman-Lin-Stadler (MULS), Travelling Current Source (TCS), and Modified Transmission Line (MTL) models, assuming similar currents at the channel base. For the assumed channel base current, all of the models gave reasonable values of fields although the charge and current distributions along the channel were quite different

for the different models. Nucci et al. [1] also discuss the reasons for the differences in the calculated fields for the different models and the ability of the models to reproduce the measured characteristics of the fields. Nucci et al. [1] did not deal with the influence of the variability of the channel base current on the predictions of the models, but a general discussion on the subject is available in Cooray and Orville [3], though not specific to the models discussed here. Also, Diendorfer and Uman [2], after introducing a new model (henceforth called the DU model), discuss the influence of the some of the channel base current parameters on the calculated fields. Although Nucci et al. [1] and Diendorfer and Uman [2] each assumed a channel base current that is typical of the measured currents for subsequent strokes in both natural and triggered lightning, the two current wave shapes differ in detail. In this paper we compare the calculated fields for the TCS, MTL, and DU models assuming both the current adopted by Nucci et al. [1] and the current adopted by Diendorfer and Uman [2] (henceforth called the Nucci current and the DU current, respectively) and show that some of the characteristics of the fields predicted by the models are very sensitive to the current waveshape assumed at the channel base and, further, that the extent of variation in the characteristics of the field depends on the specific model. Finally, we extend the DU model theoretically to include return stroke speed variation as an arbitrary function of height and present calculated fields for the specific case of an exponentially decreasing return stroke speed with height for the TCS, MTL, and DU models.

RESULTS

The Nucci current and the DU current are compared in Fig.1. The DU current has a narrower peak, a small hump after the peak, and a faster decay than the Nucci current. The small differences in peak currents and front rise times influence mostly the field rise times and peaks and do not influence significantly the overall wave shape of the fields. For field calculation with the MTL model a current decay constant of 2000 m is assumed which is the same as in Nucci et al. [1]. When fields are calculated with the DU model, two time constants, 0.6 μs and 5.0 μs, are adopted just as in Diendorfer and Uman [2]. Fig.2 shows the electric fields at a distance of 100 km for the DU current and the Nucci current and a constant return stroke speed of 1.3e08 m/s. From Fig.2a it is seen that with the DU current at the channel base the TCS model field (line 2) crosses zero around 50 μs while it does not cross zero within 100 μs with the Nucci current (curve 5). Similarly, the DU model field crosses zero around 55 μs with the DU current at the channel base (curve 3) while it does not do so within 100 μs with the Nucci current (curve 6). The choice of base current does not appreciably affect the zero crossing time (around 30 μs) of the MTL model fields (curves 1 and 4). Also note that for the given channel base current the TCS and DU model fields are different only for the first 30 μs or so, and after that they are almost the same with the DU fields being slightly higher. Fig.2b shows the same fields as in Fig.2a for the first 5 μs. The initial peak fields are higher with the DU channel base current for all the models. The initial peak fields are the smallest for the DU model, less than half of the TCS model values and slightly greater than half of the MTL model values. Figs.3a and 3b show, respectively, the electric and magnetic fields at a distance of 5 km for the models with a constant return stroke speed of 1.3e08 m/s and with DU and Nucci currents at the channel base. For a given model the fields produced by the DU current at the channel base are larger for the first few tens of

microseconds, but becomes less than the fields produced by the Nucci current at the channel base at later times. For a given base current the electric fields produced by the TCS and DU models are very similar (see the pairs 2, 3 and 5, 6 of Fig.3a) after about 20 μs, with the electric fields of the TCS model always being larger than the corresponding DU model electric fields. The magnetic fields for the TCS and the DU models are roughly equal after about 40 us for the given channel base currents (see Fig.3b). Also for the fields at 5 km, the magnetic hump after the initial peak of the TCS model is more prominent with the DU current than with the Nucci current (see Fig.3b).

The DU model was derived for a constant return stroke speed in Diendorfer and Uman [2]. The DU model can be generalized to include a variable return stroke speed that is an arbitrary function of height. It can be shown mathematically [4] that the return stroke channel current $i(z',t)$, where z' is the height above the ground, is given by

$$i(z',t) = i(0,t+z'/c) - i(0,z'/V_{av}(z')+z'/c) * \exp[-(t-z'/V_{av}(z'))/\tau] \quad (1)$$

where $V_{av}(z')$ is the return stroke speed averaged over a height z' defined by

$$V_{av}(z') = \frac{z'}{\int_0^{z'} \frac{dz''}{V(z'')}} \quad (2)$$

c, the speed of light, and τ, the time constant for discharging the charge on the leader. An exponential decrease in speed given by

$$V(z') = V*\exp[-(z'/\lambda)] \quad (3)$$

where V is the speed at ground level. The factor λ in equation (3) is a constant whose value is chosen as 2000 m. The speed at ground level is taken as 1.3e08 m/s for all three models. The DU current is assumed at the channel base for the purpose of comparing the fields produced from the constant speed case with the variable speed case. The other parameters of the three models are the same as previously given.

Fig.4 shows the effect of an exponentially decreasing speed on the electric fields produced by TCS, MTL, and DU models at 100 km. The zero crossing time of the TCS and DU models are earlier by about 15 μs (compare curves 2, 3 with 5, 6 respectively), but the zero crossing time of the MTL model is not affected very much. Also the hump after the peak of the TCS and DU model fields are less prominent with a decreasing speed.

DISCUSSION

After a time of about 35 μs the DU channel base current amplitude is smaller than the corresponding Nucci current and at 100 μs the DU current is only about half of the Nucci current. The lower channel base currents at later times results in lower currents along the channel at later times for all the models. Hence the fields produced at 5 km by a given model for the DU current at the channel base are smaller than the fields produced by the Nucci current at the channel base after the first few tens of microseconds. The fields at 100 km are dominated by the radiation term caused by the time rate of change of current all along the channel. As discussed in Nucci et al. [1], the time derivative of the current is positive at the return stroke wave front for the TCS and MTL models and negative at all points below the wave front for the TCS model and a few meters below the wave front (because of the finite rise time of the current) for the MTL model. For the DU model the time derivative of the current is positive at the wave front and a few meters below it and negative at all

other points. The fields at 100 km cross zero at the time that the contribution to the fields from the negative current derivatives become dominant. The amplitude of the derivative of the current is determined by the amplitude, rate of rise, and rate of decay of the current. With the DU current at the channel base, the amplitude of the currents at later times along the channel are smaller for all the models, and hence there are earlier zero crossing times (by more than 50 μs) for the TCS and DU models. The zero crossing time of the MTL model is not very sensitive to the channel base current because in the MTL model, as the current from ground travels up the channel, it decays exponentially and the current value and its derivative at the top sections of the channel are only a small fraction of their values at the bottom sections, irrespective of the current at ground. For the same return stroke speed at ground, a decreasing speed with height delays the time at which the return stroke wave front reaches a given height, which in turn causes the smaller currents at the tail of the channel base current to appear at lesser height when compared to the constant speed case. This also causes the field at 100 km to cross zero earlier (by about 15 μs for an exponential speed decay constant of 2000 m) for the TCS and the DU models. The zero crossing of the MTL model is not very sensitive to the assumed variation in speed for same reason mentioned above.

CONCLUSION

The fields calculated by the three return stroke models studied are sensitive to the channel base current characteristics and to the return stroke speed, but the different models respond in varying degrees to the above parameters. The differences in the predictions may be experimentally measurable. In that case, design of an experiment for the simultaneous measurement of the return stroke speed, the channel base current for long duration, and the fields, both close and far from the channel might allow a determination of the best existing model or could make possible the development of a better model.

ACKNOWLEDGEMENT

This research was supported in part by NSF grant ATM 8807449 and by the U.S. Department of Energy, Office of Energy Management, under contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems.

REFERENCES

[1] Nucci C. A., G. Diendorfer, M. A. Uman, F. Rachidi, M. Ianoz, and C. Mazzetti, Lightning return stroke current models with specified channel-base current: a review and comparison, J. Geophys. Res., 95, 20395-20408, 1990.

[2] Diendorfer G. and M. A. Uman, An improved return stroke model with specified channel-base current, J. Geophys. Res., 95, 13621-13644, 1990.

[3] Cooray V. and R. E. Orville, The effects of variation of current amplitude, current rise time, and return stroke velocity along the return stroke channel on the electromagnetic fields generated by return strokes, J. Geophys. Res., 95, 18617-18630, 1990.

[4] Thottappillil R., G. Diendorfer, and M. A. Uman, Extension of the Diendorfer-Uman lightning return stroke model to the case of a variable return stroke speed, Submitted Nov. 1990 to the J. Geophys. Res..

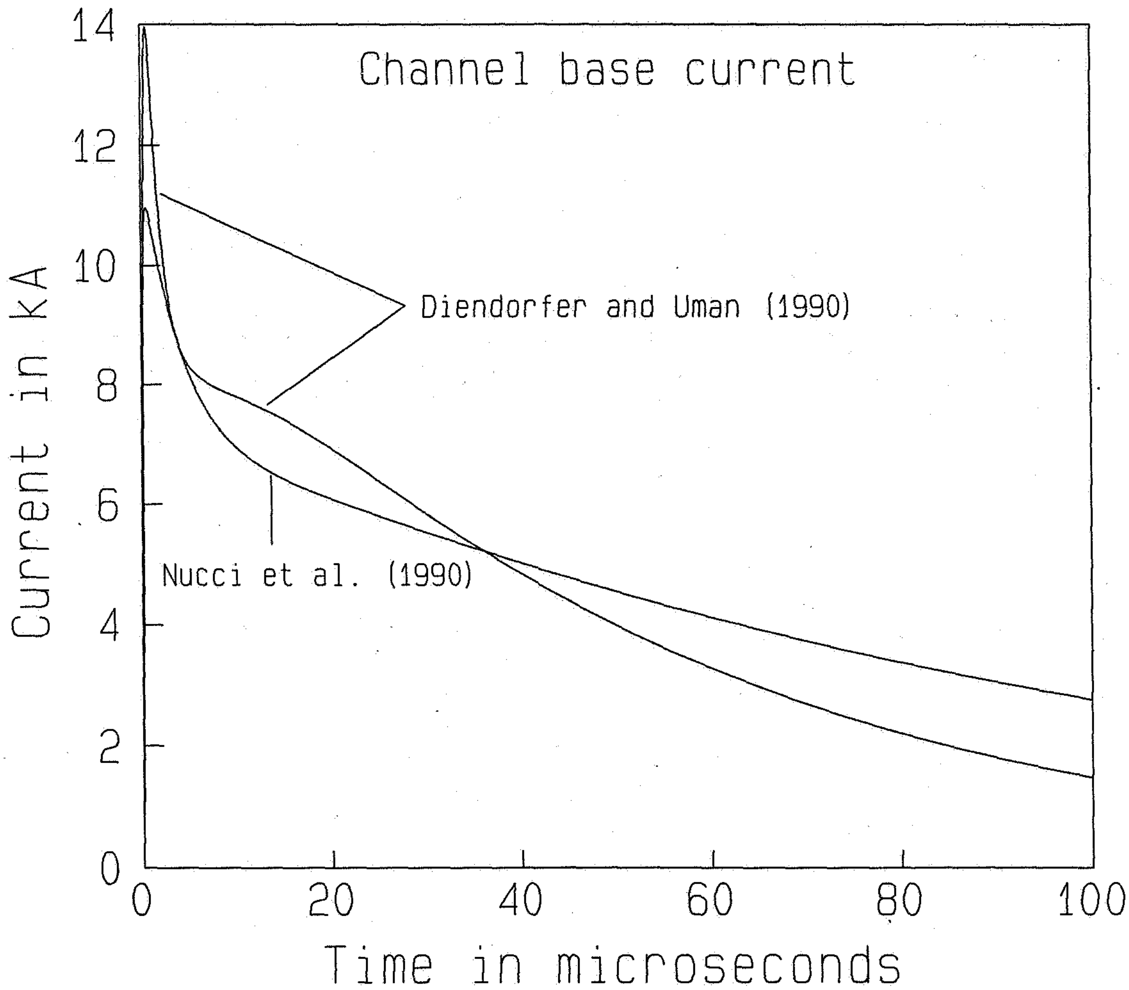

Fig.1 Channel base currents

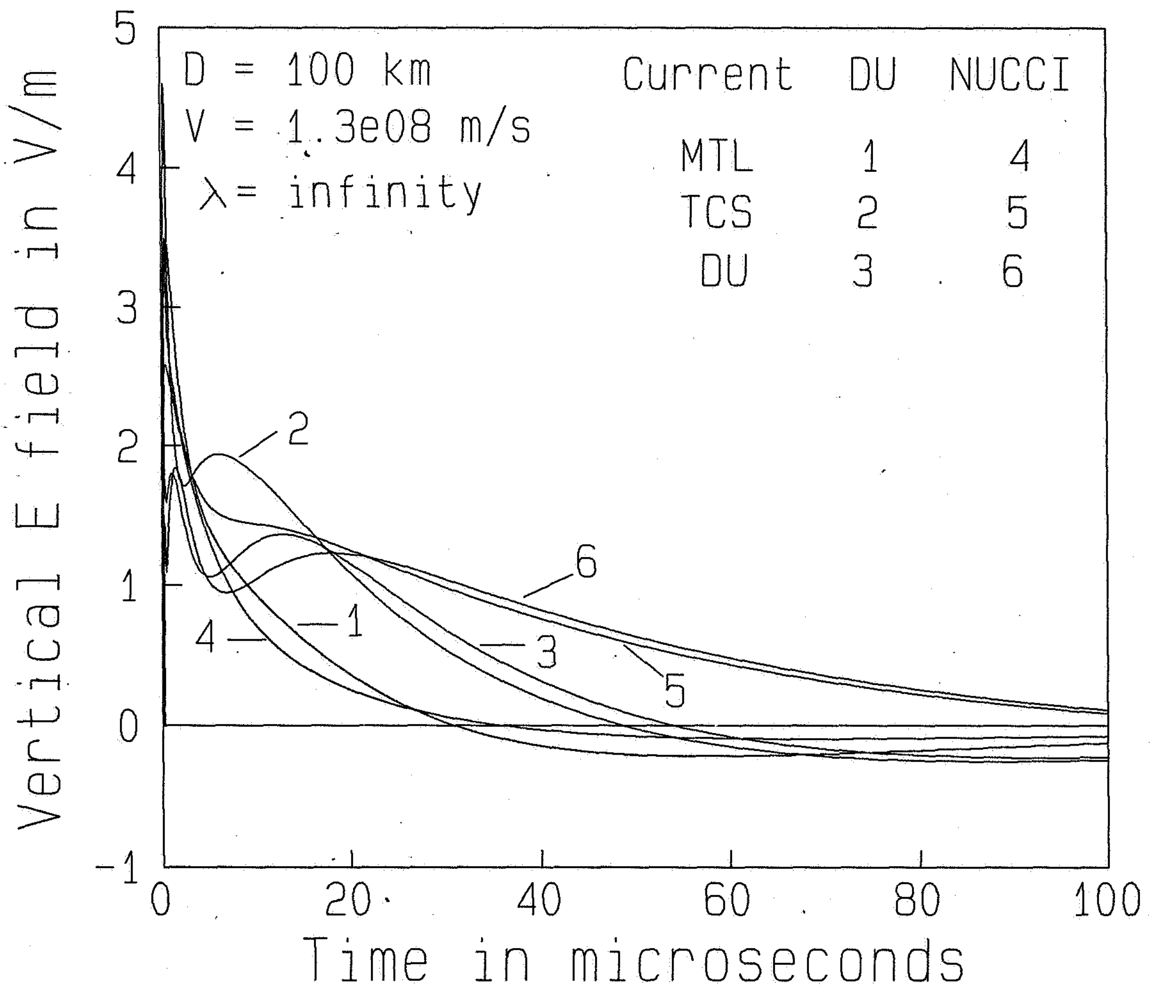

Fig.2a Electric fields at 100 km of the MTL, TCS, and DU models with currents shown in Fig.1 at the channel base. Note the difference in time at which the fields cross zero.

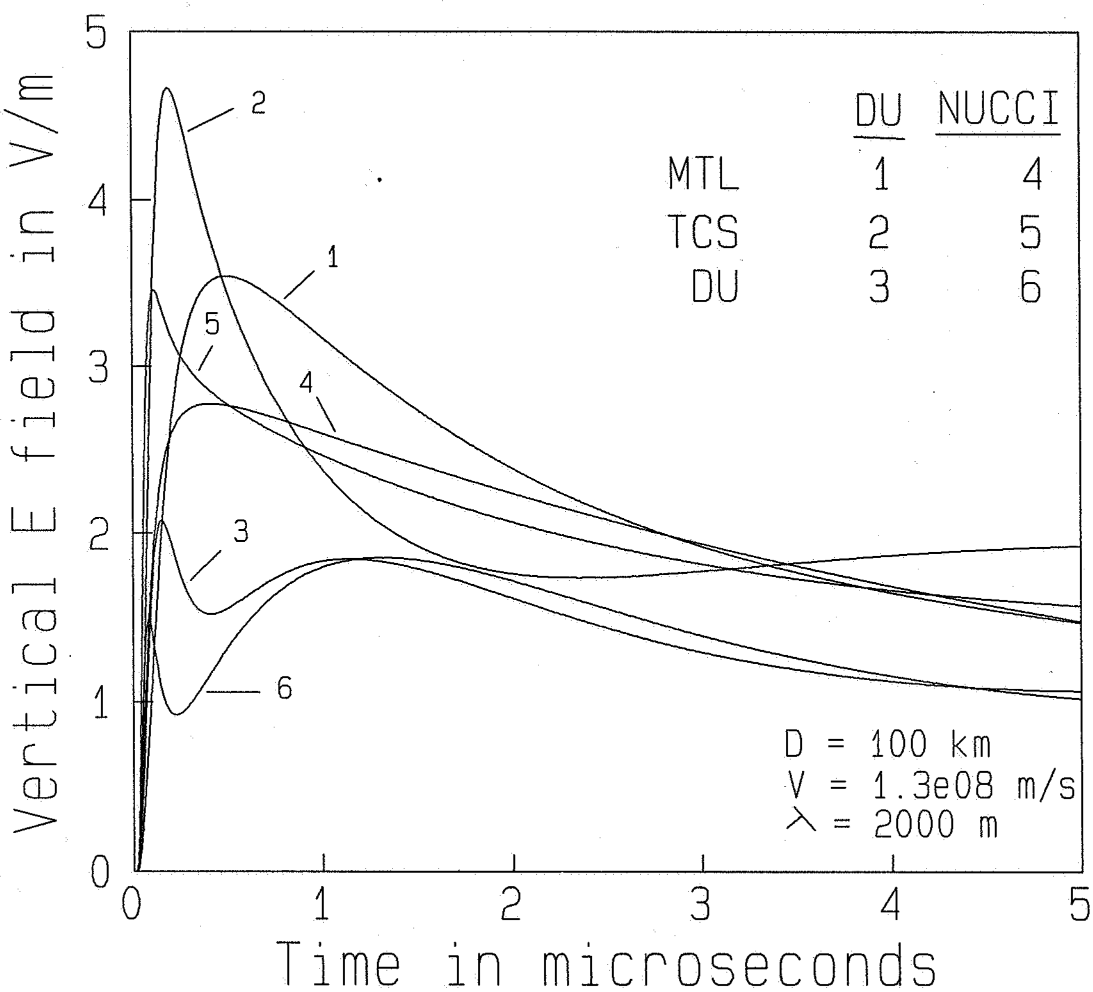

Fig.2b Electric fields at 100 km of the MTL, TCS, and DU models with currents shown in Fig.1 at the channel base. Note the difference in the initial peaks.

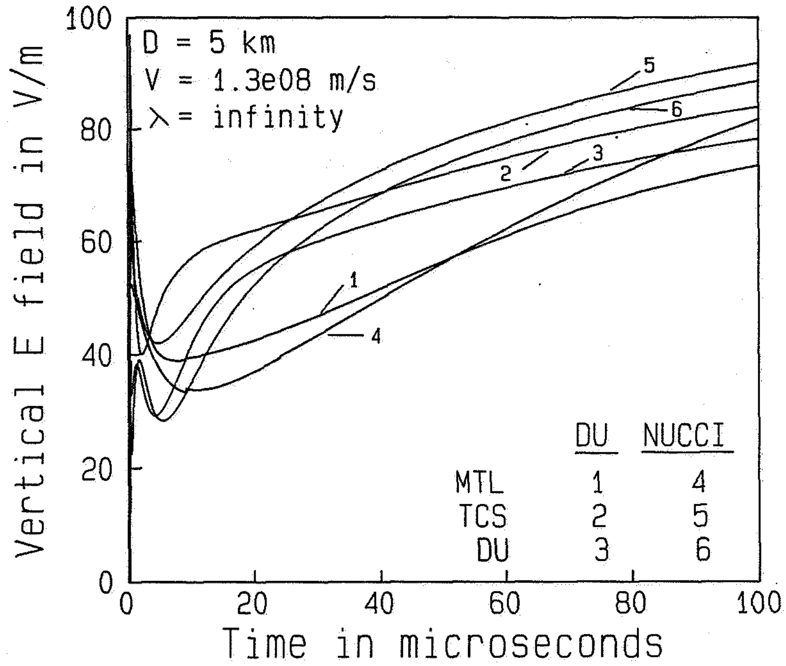

Fig.3a Electric fields at 5 km of the MTL, TCS, and DU models with currents shown in Fig.1 at the channel base.

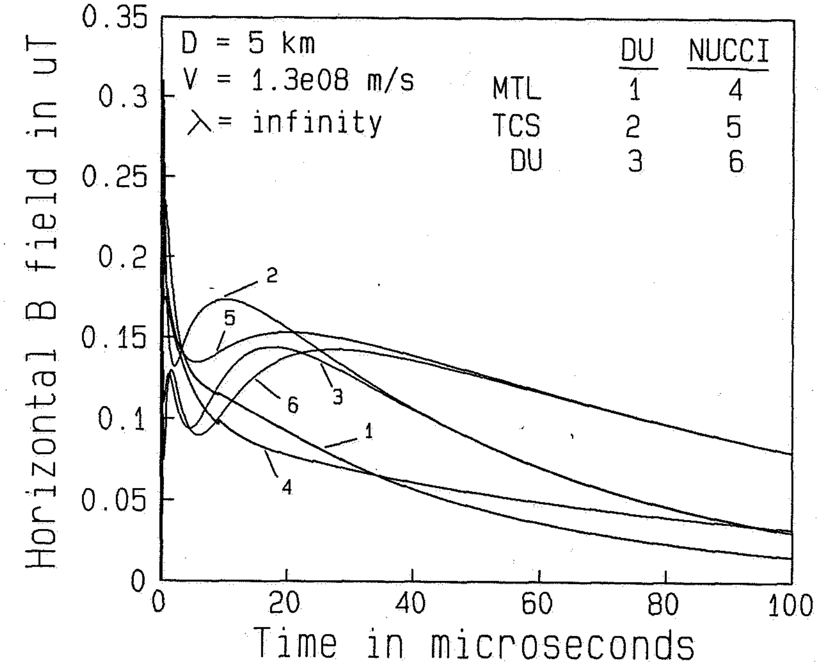

Fig.3b Magnetic fields at 5 km of the MTL, TCS, and DU models with currents shown in Fig.1 at the channel base.

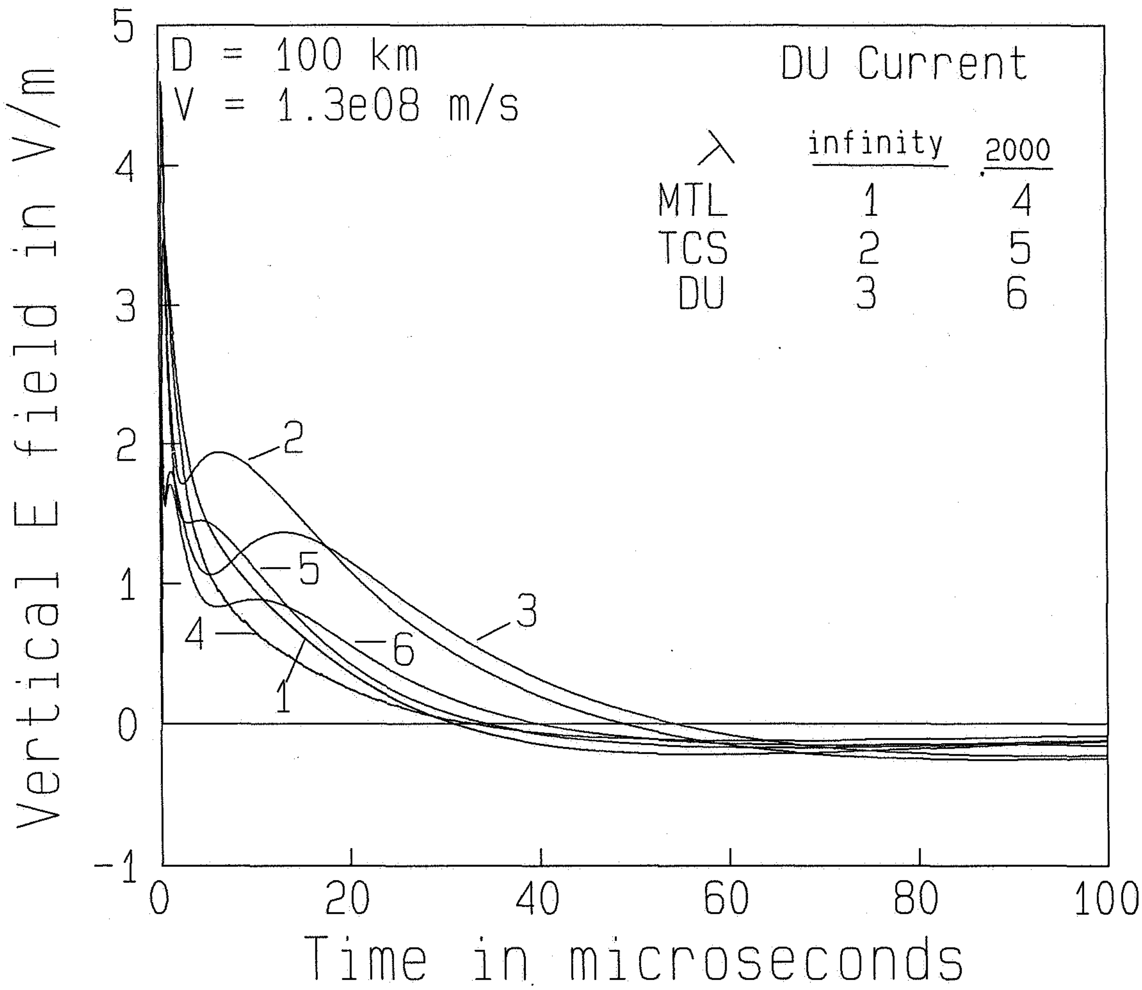

Fig.4 Electric fields at 100 km of the MTL, TCS, and DU models with DU channel base current for the cases of constant return stroke speed and decreasing return stroke speed with height.